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Comparison of an actuator disc model with a full Rotor CFD model under uniform and shear inflow condition

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The goal set for this project is to compare qualitatively the wake features observed in two fundamentally different approaches to model the air flow around wind turbines. The comparison is carried on under two inflow conditions, one with a uniform profile, and one with a shear inflow. The main interest of this comparison is to gain knowledge from the level of details the actuator disc in comparison to the full rotor CFD model. This type of qualitative study can help to establish guidelines for using adequately the actuator disc model. A special focus is put on the wake rotational effect and its interaction with the shear in the near and far wake regions.

The full rotor CFD model resolves the actual blade and tower geometry of the wind turbine in the computational mesh. A full resolution of the boundary layer on the blades gives an accurate estimation of the forces acting on the rotor as well as an accurate description of the wake expansion downstream the wind turbine. The model uses an overset grid method to handle the relative movement between the rotor, tower and ground boundary.

The actuator disc model is based on a discretization of the forces acting on the wind turbine blades, radially averaged over the rotor area. This eliminates the need to resolve the blade boundary layer, greatly reducing the size of the computational mesh. The discrete forces implementation in the Navier Stoke Equations is carried on by body forces compensated by cell-face pressure jumps (Réthoré and Sørensen 2008). The forces assigned on the disc are extracted from the full Rotor CFD model.

Comparison of an Actuator Disc model with a Full rotor computation

Pierre-Elouan Réthoré

Frederik Zahle

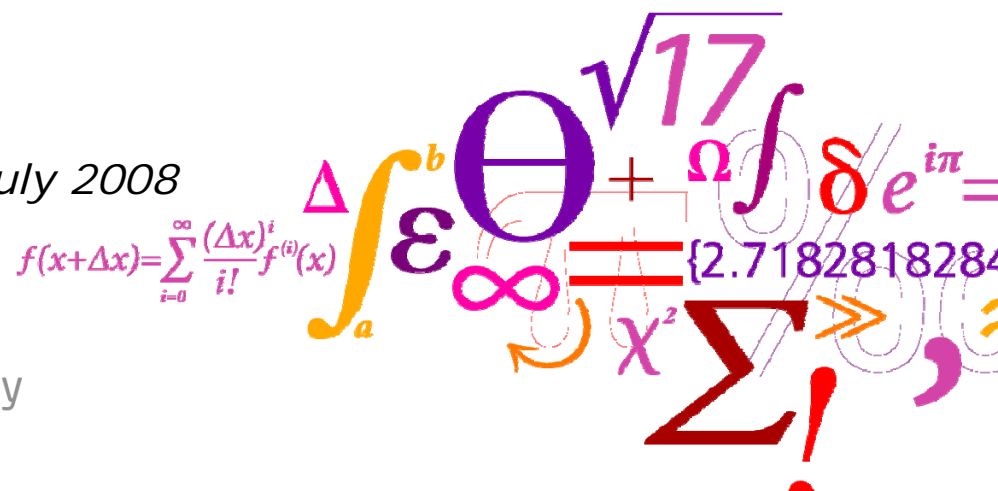
Niels N. Sørensen

Jeppe Johansen

Wake workshop – Oldenburg – July 2008

Risø DTU

National Laboratory for Sustainable Energy



Actuator disc model in CFD

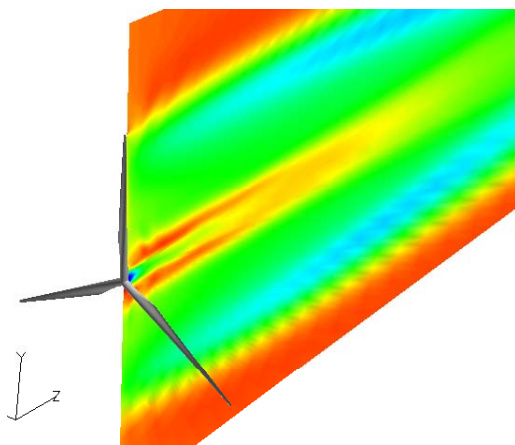
introduction

- Mature technology: more than 20 years of research on the subject.
- Relatively intuitive: body forces model the action of turbines on the wind.
- But there are a lot of decisions to make on how to prescribe them:
 - Constant/variable loading?
 - Discreet/Gaussian force distribution?
 - Wind speed/direction shear?
 - Wake rotation?
- And how to model the flow:
 - What kind of ground modeling?
 - What kind of turbulence modeling?
 - What kind of inflow turbulence?
 - Wake meandering model?
- All these choices have an impact on the wake development, and on the mesh complexity (proportional to computational time). So which ones are important in the wind farm wake context?

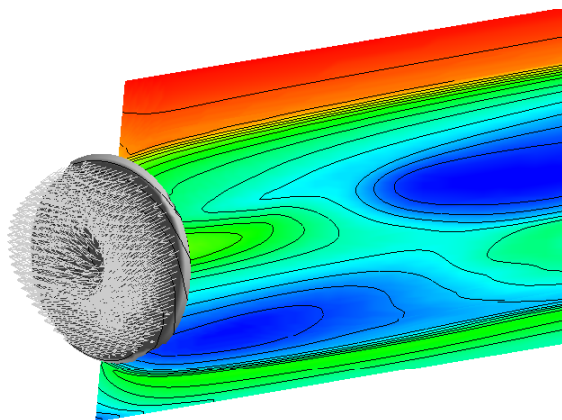
Actuator disc model in CFD

The intermediate model

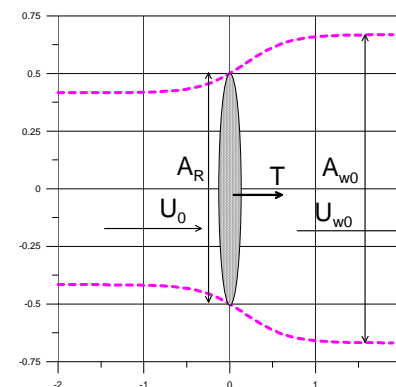
- The actuator disc model is a good intermediate model to test what are the correct assumptions to design a good engineering wind farm wake model.



Full rotor models
1-CPU time: months



Actuator disc models
1-CPU time: hours



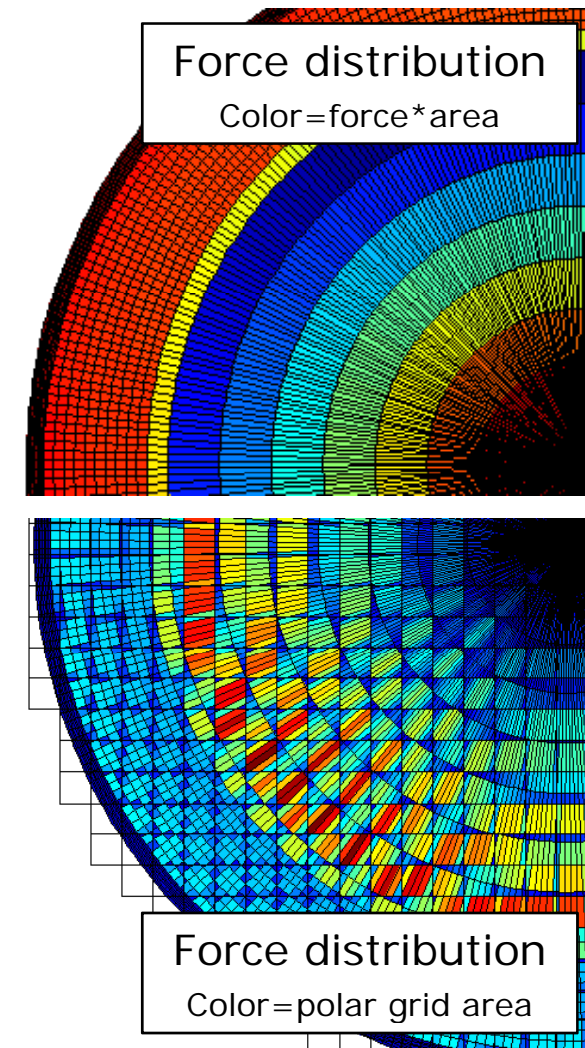
Engineering models
1-CPU time: seconds

How to compare – what to compare?

- The comparison is focussed on how to distribute the loads, and the impact on the wake development.
- The loads are determined by pressure integration at different positions on the blade in the Full Rotor Computations. They are then redistributed over the actuator disc.
- Three load distributions tested:
 - **Wake rotation:** Identical loading, smeared over the disc
 - **No wake rotation:** Idem, but only the axial forces are kept
 - **Constant CT:** The forces are distributed uniformly over the disc
- Same ground model, same inflow conditions, same turbulence model (k- ω).
- Comparison of the wake development (axial velocity, turbulence kinetic energy).

How to distribute the loads?

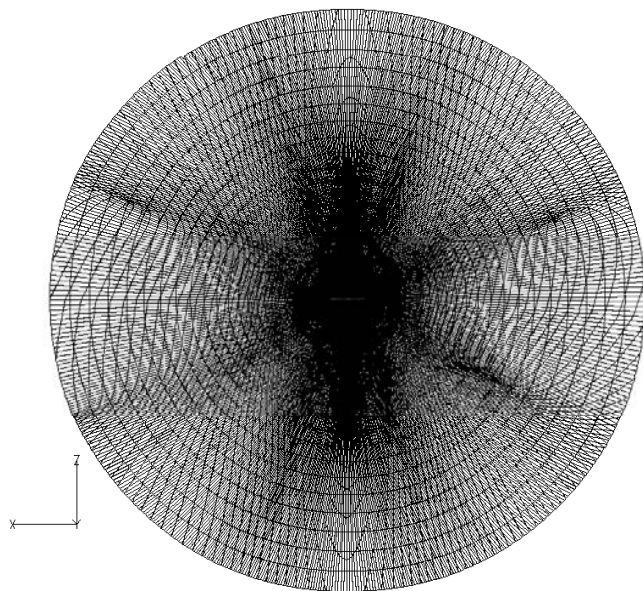
- Axially: The forces are distributed over 3 cells, with a pressure jump at the cell faces to compensate the pressure/velocity decoupling.
- Radially:
 - The force history of a rotor revolution is smeared over a polar grid.
 - The contribution of each polar grid element is added proportionally to the intersectional area with the computational mesh.
 - For the 3 different cases
 - **Wake rotation:** 3 components
 - **No wake rotation:** axial component
 - **Constant CT:** $F = -\frac{1}{2} \rho U_{\infty}^2 C_T Area$



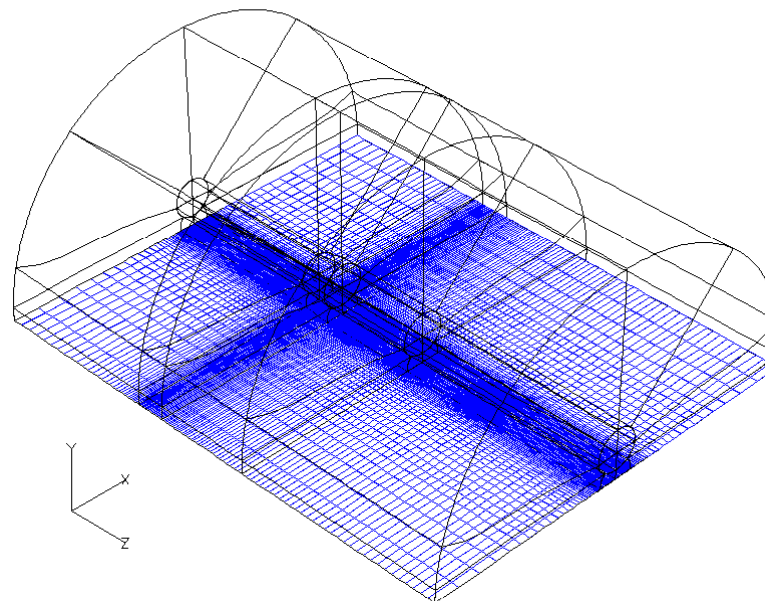
Full rotor computations

What is available

- The two models availables to compare are based on two different meshes and inflow conditions.



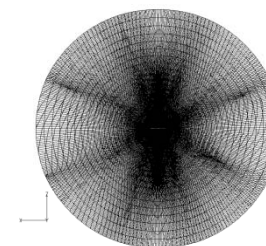
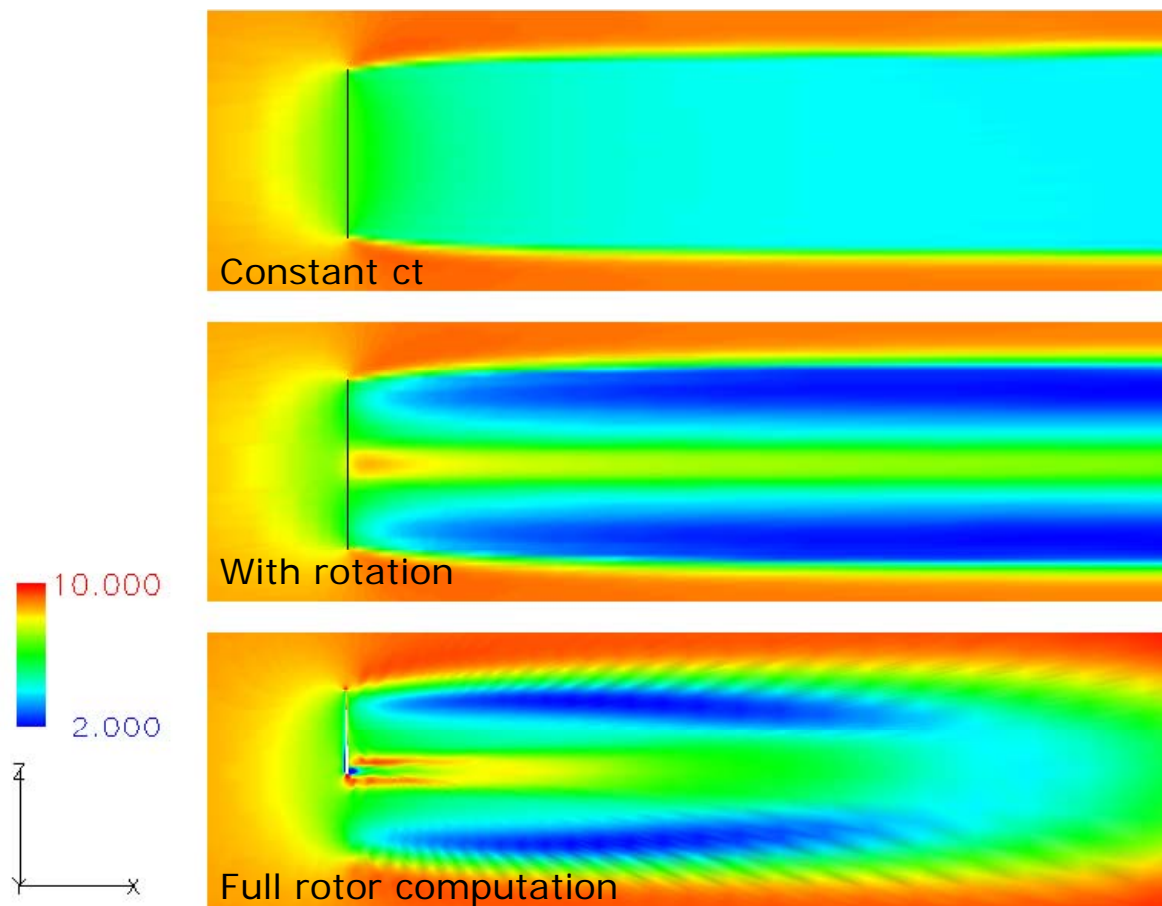
Uniform inflow. Spherical domain. Traditional grid. 5D of wake. No ground. Steady state solution. Very high numerical wake dissipation



Shear inflow. Cylindrical domain. Oversetting grids. 5D of wake. Symmetrical ground boundary. Transient solution. Overpredicted forces.

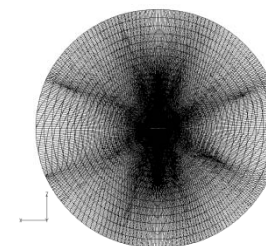
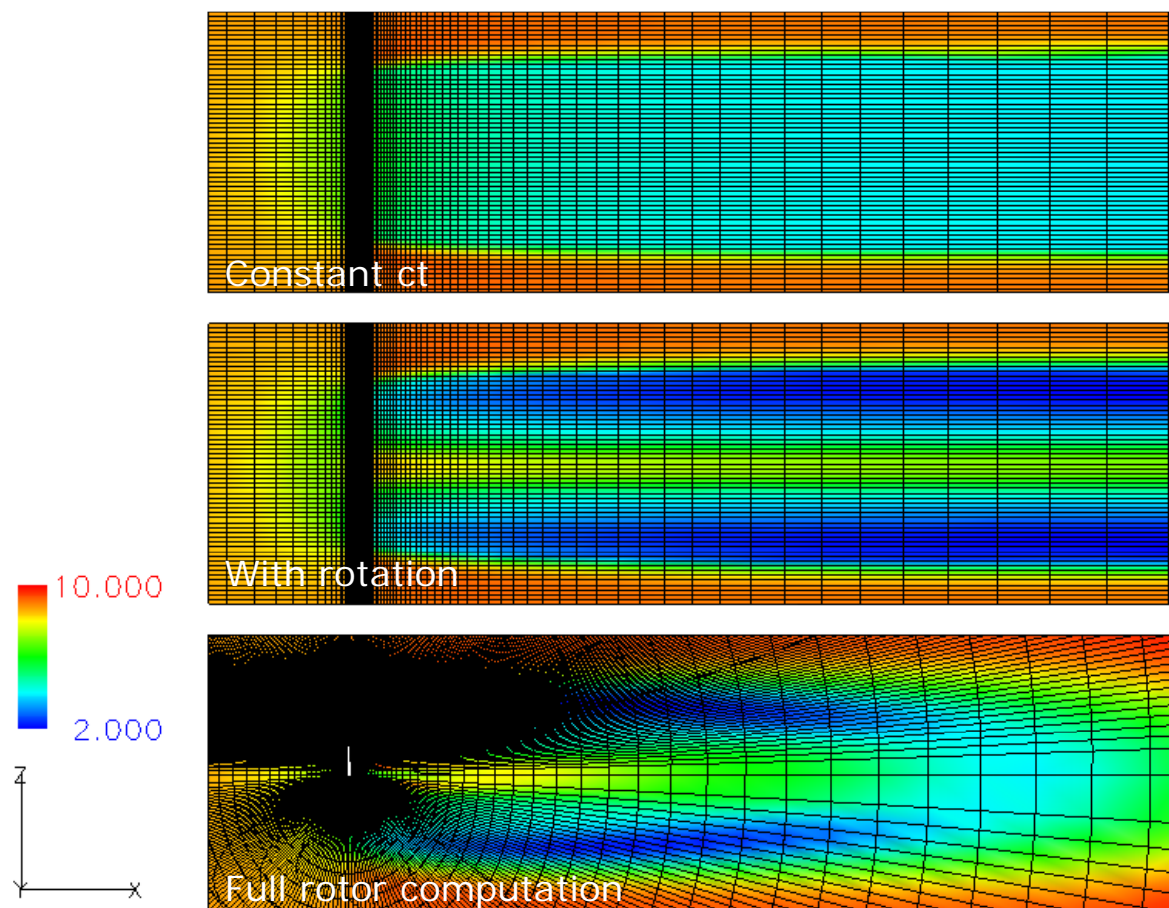
Uniform inflow case: preliminary results

Axial velocity



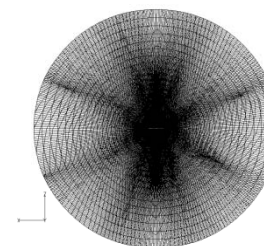
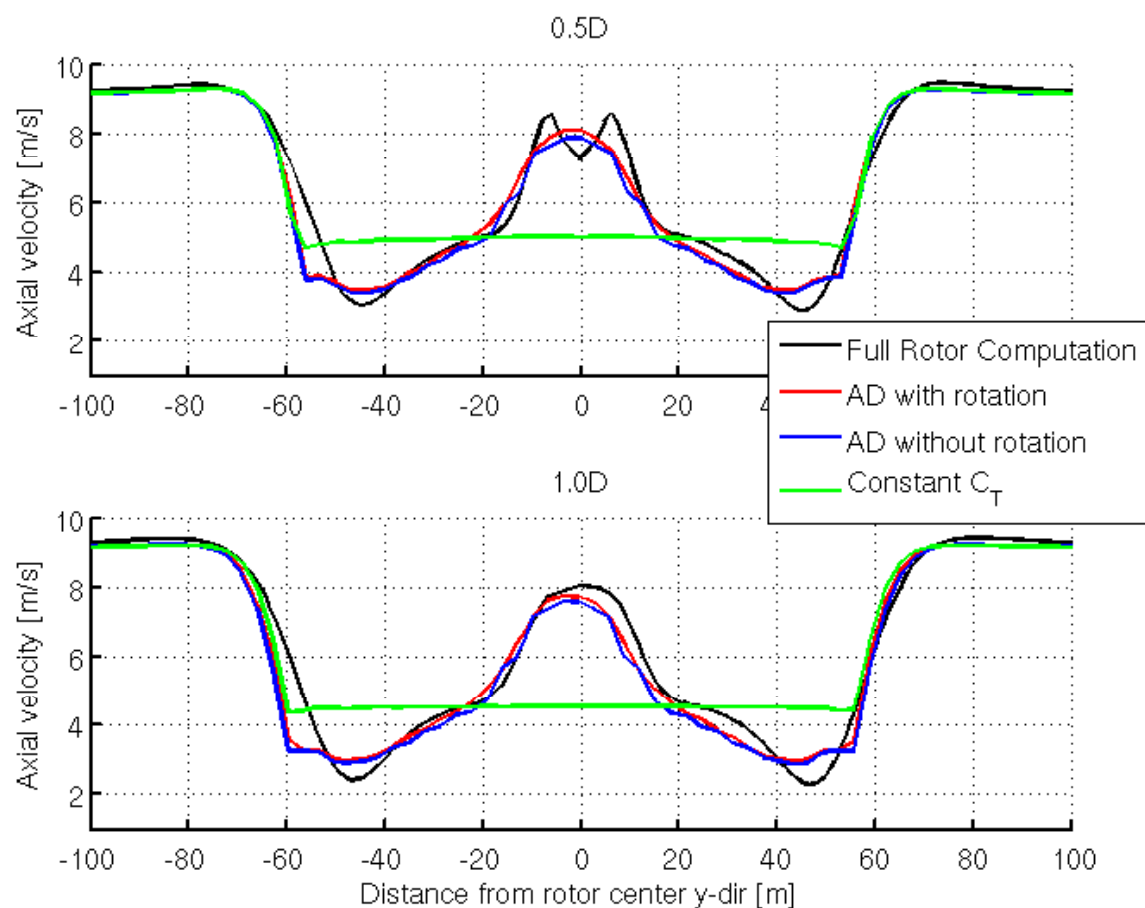
Uniform inflow case: preliminary results

Mesh spacing



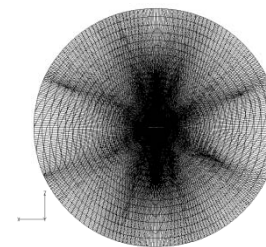
Uniform inflow case: preliminary results

Axial velocity



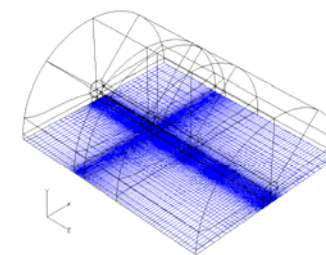
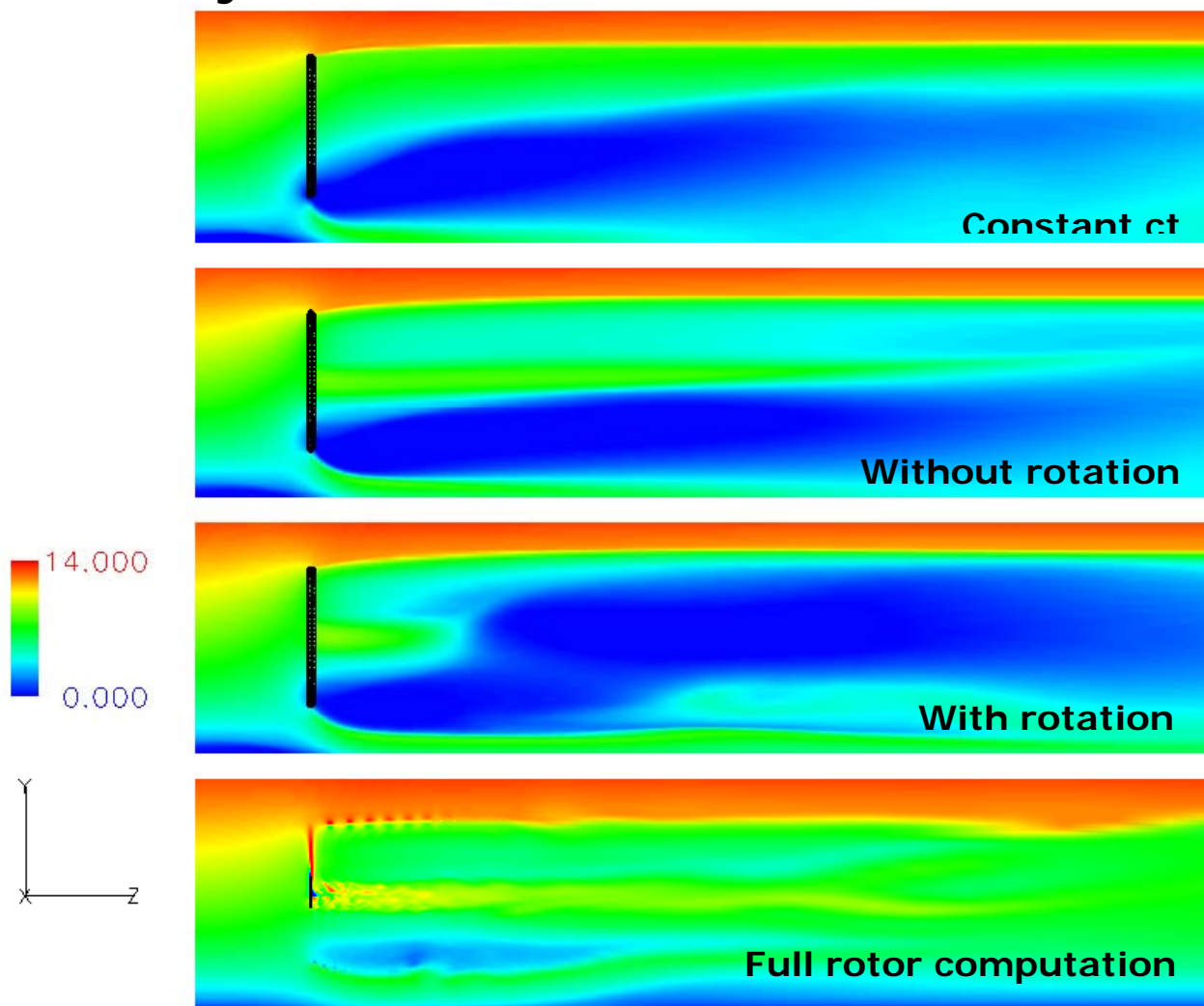
Uniform inflow case: future directions

- Future full rotor computations using with a cylindrical mesh more adapted for wake computation
- Does the wake rotation affect the wake development on the long run?



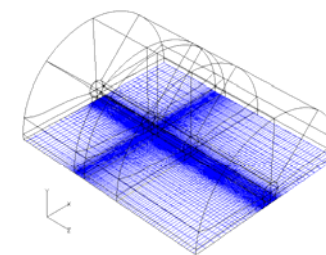
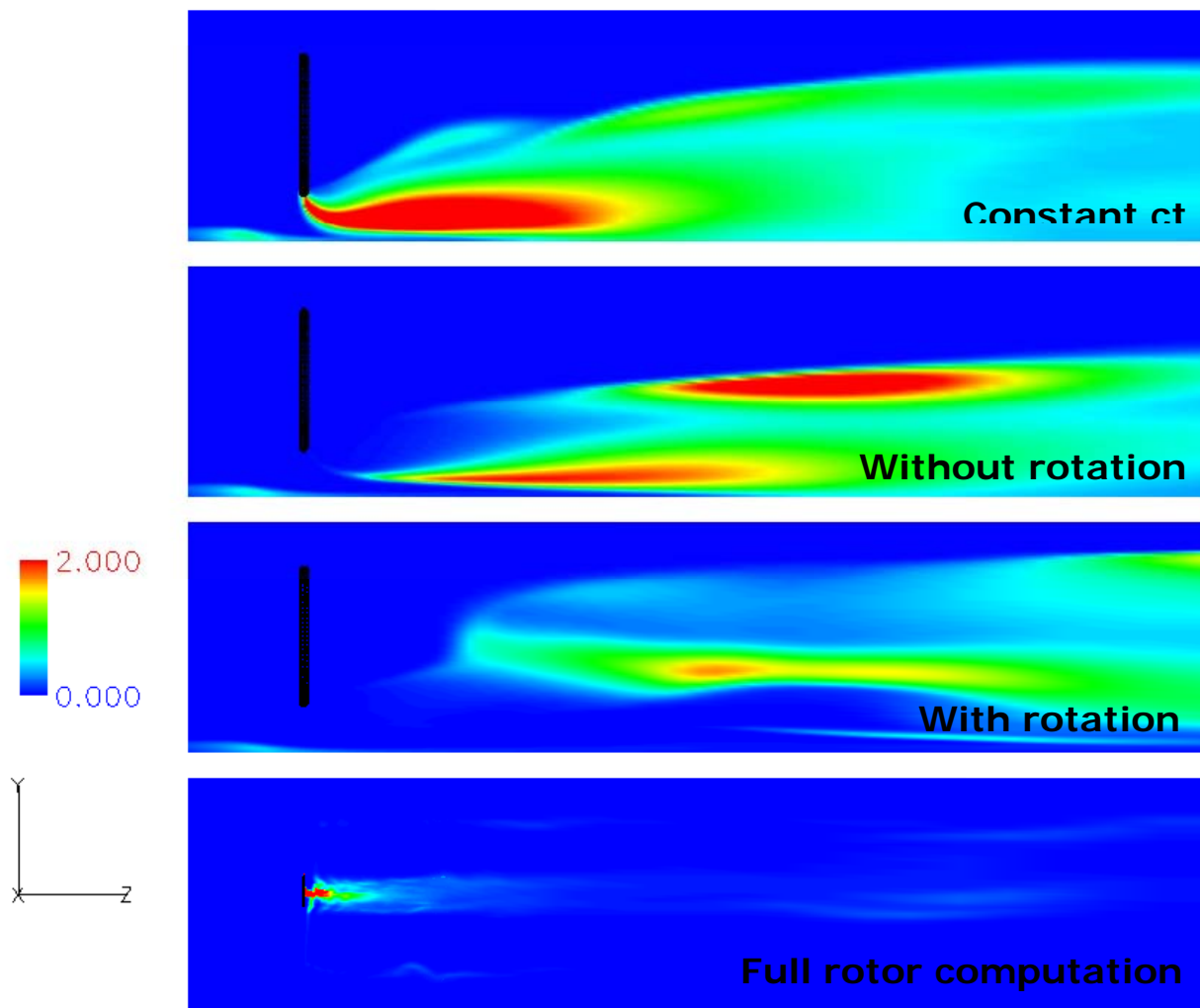
Shear inflow case: preliminary results

Axial velocity



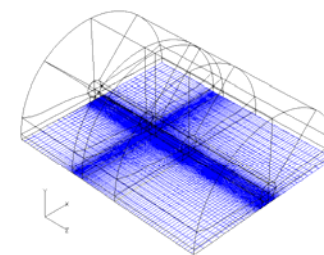
Shear inflow case: preliminary results

Turbulence Kinetic Energy



Shear inflow case: future directions

- Full rotor computations at a lower CT (with k-omega SST)
- Different ground models
- Different turbulence models
- Different the force distributions (uniform CT / wake rotation)
- Wind direction shear
- Different stability cases



$$f(x+\Delta x)=\sum_{i=0}^{\infty}\frac{(\Delta x)^i}{i!}f^{(i)}(x)$$

$$\Delta \int_a^b \varepsilon \Theta + \Omega \int \delta e^{i\pi} = \sqrt{17} \int \delta e^{i\pi} = \{2.7182818284\}$$

$$\infty = \chi^2 \sum \gg \Sigma !$$